Tracking Detectors Based on CVD Diamonds

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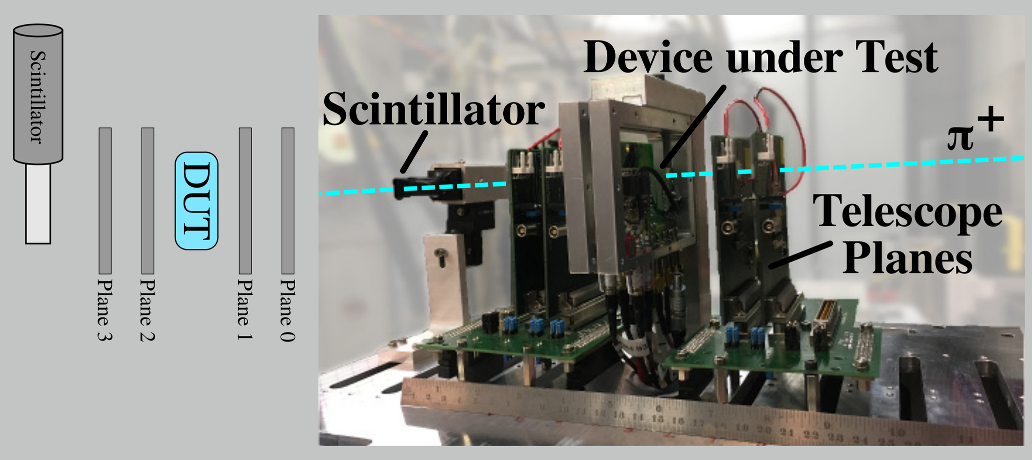
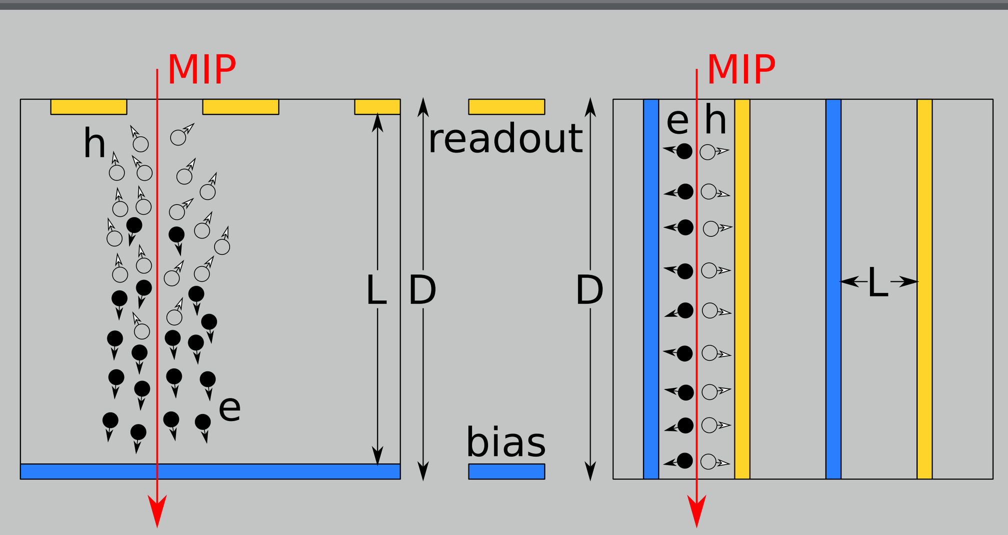
Setup



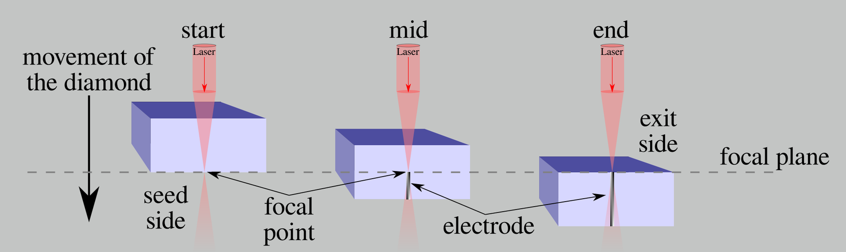
- particle beam to investigate DUTs (devices under test)
- beam "telescope": information where particles hit the DUT
- telescope: two pixelated planes before and after the DUT
- 4160 pixel à 150 µm × 100 µm per each plane
- fast scintillator at the end for precise trigger timing $\mathcal{O}$ (5 ns)

3D Detectors

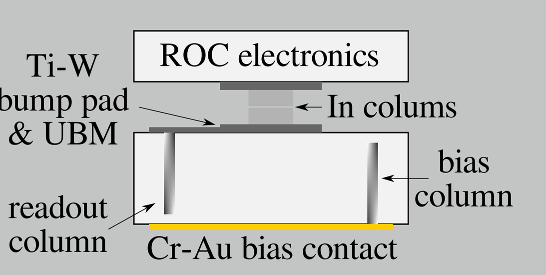
Detector & Fabrication



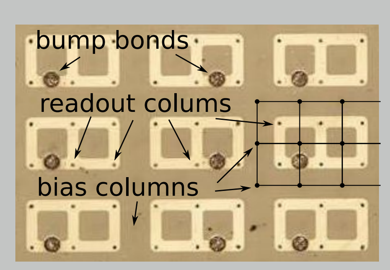
- 3D = bias and readout electrode inside detector material
- same thickness D → same induced charge → shorter drift path L
- increase collected charge in detectors with limited mean drift path
- introduce low field regions



- "drilling" columns using 800 nm fs-LASER
- convert diamond into resistive mixture of carbon phases (i.a. DLC)
- column yield: $\gtrsim$99.8 %
- column diameter: 2.6 µm



(a) Bump bond schematics



(b) 3 × 2 bump pads

- connection to bias and readout with surface metallisation
- ganging of cells to match pixel pitch of readout-chip (ROC)
- small gap (∼15 µm) to the surface
- bump bonding to pixel readout chip

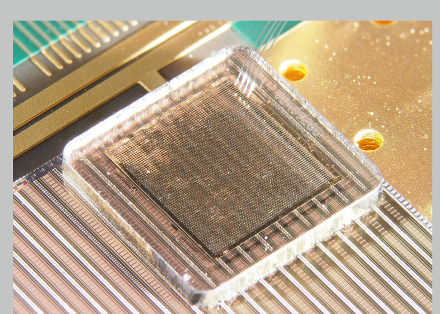


Figure: Final detector on a readout chip.

Analysis

- pixel readout chip provides pixel hits with pulse height
- need to apply cuts to select meaningful events
- cuts applied in order of the following table

Cut	Excluded Events
event range	first minute of the run due to various beam conditions
beam interruptions	during rate changes of the beam due to beam interruption
aligned	DUT and Telescope are not aligned (event-wise)
trigger phase	Chip trigger timing is incorrect
tracks	not all telescope planes have exactly one cluster
chi2 (x/y)	badly fit tracks (>50 % quantile)
track slope (x/y)	large angles of the tracks (>2 deg)
rhit	large DUT residual (>100 mm)
pixel mask	noisy pixels
fiducial	not in selected (fiducial) area of the DUT

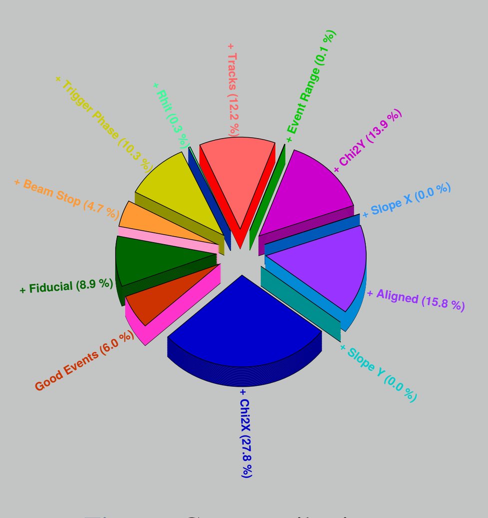


Figure: Cut contributions.

Pad Detectors

Detector & Fabrication

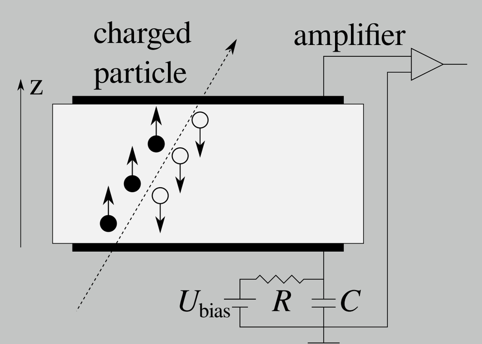
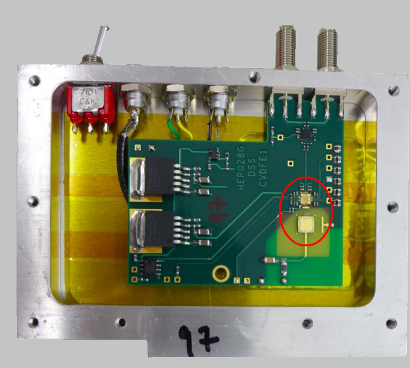
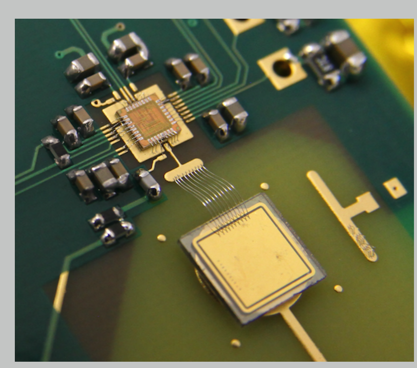


Figure: Detector Schematics

- detectors operated as ionisation chambers
- metallisation on both sides + readout = detector



(a) Detector Box

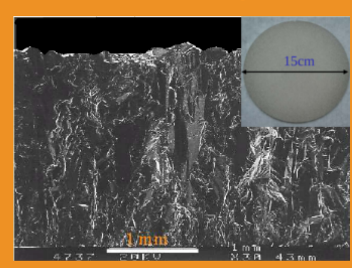


(b) Pad Detector with Amplifier

- cleaning, photo-lithography and Cr-Au metallisation
- gluing to PCBs in custom built amplifier boxes
- connecting to low gain, fast amplifier with $\mathcal{O}$ (5 ns) rise time

CVD Diamonds for Tracking

- inner tracking layers of future detectors → extreme radiation damage $\mathcal{O}$ (GHz/cm^2)
- R&D for more radiation tolerant detector designs and/or materials
- investigation of diamond as a future material for tracking detectors
- diamonds artificially grown with chemical vapour deposition (CVD)
- poly crystalline (pCVD) diamonds available in wafers of 15 cm diameter



Properties of Diamonds:

Value	Silicon	Diamond	Property
Band Gap [eV]	1.12	5.45	low leakage current
Electron Mobility	1450	2200	fast signals
Hole Mobility	500	1600	fast signals
Resistivity [Ω cm]	$2.3 \cdot 10^5$	$>10^{11}$	low leakage current
Dielectric Constant	11.9	5.7	low input capacitance
Displacement Energy [eV]	13-20	43	radiation tolerant
Thermal Conductivity [W/cmK]	1.5	22	no cooling
e-h Creation Energy [eV]	3.6	13	low signals
e-h pairs per MIP per µm	89	36	low signals

- smaller signal than in silicon with same thickness (large bandgap)
- after $1 \cdot 10^{16}$ n/cm^2 the mean drift path in diamond larger than in silicon

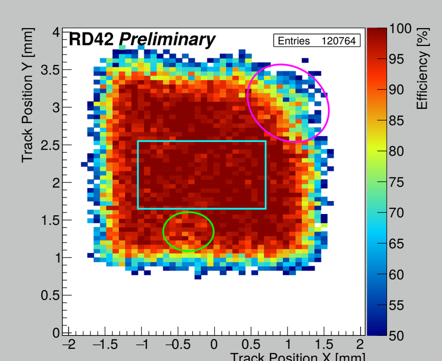
Research Goals:

- measure signal dependence of pCVD diamond detectors on incident particle flux using a pad detector geometry
- investigate novel detector design of a 3D geometry as potential candidate for future tracking detector

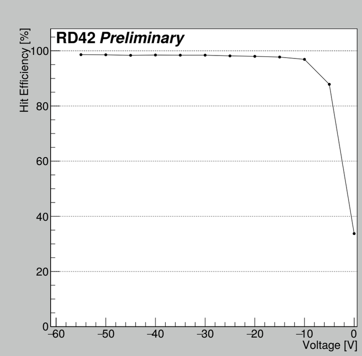
Results

- built two very similar 3D detectors on different readout chips

	B5	B6
readout chip (ROC)	FE-I4B	PSI46digv2.1respin
pixel pitch	250 µm × 50 µm	150 µm × 100 µm
3D cell size	50 µm × 50 µm	50 µm × 50 µm
ganging	5 × 1	3 × 2
size	4.90 mm × 4.94 mm	4.85 mm × 4.90 mm
thickness	510 µm	500 µm
50 pixels × 50 pixels	53 × 67	67 × 53
3D columns	7223	7223
column diameter	2.6 µm	2.6 µm
active area	3.2 mm × 3.5 mm	3.45 mm × 3.19 mm
bump bonding	tin silver (IFAE)	indium (Princeton)



(a) Efficiency Map



(b) Efficiency vs. voltage.

- telescope tracking resolution at DUT: $\mathcal{O}$ (100 µm)
- magenta area → bump bonding problems
- green area → void in the diamond
- efficiency in blue box: 99.2 % (→ 99.6 % expected due to columns)
- efficiency already plateaus at 30 V

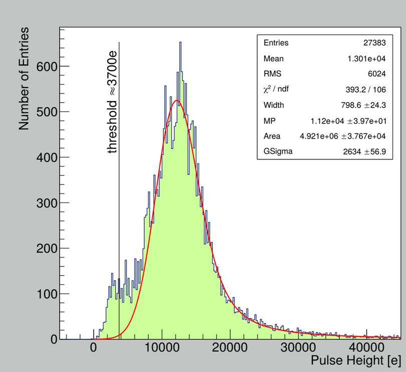


Figure: Pulse height distribution.

- threshold of the chip: ∼3700 e
- mean from MC of Langau fit: ∼14 500 e
- distribution below threshold not understood

Analysis

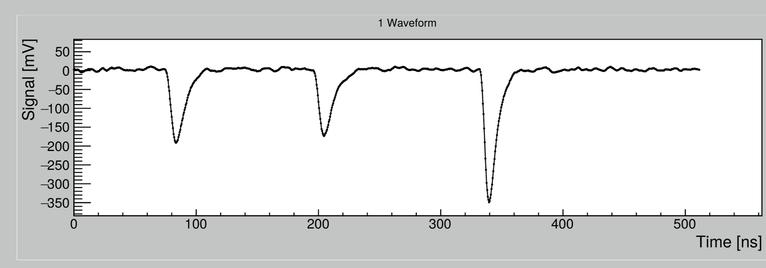


Figure: Raw waveform.

- digitised diamond waveforms with DRS4 Evaluation Board at 2 GS/s
- DRS4 memory cells vary in size → timing correction required

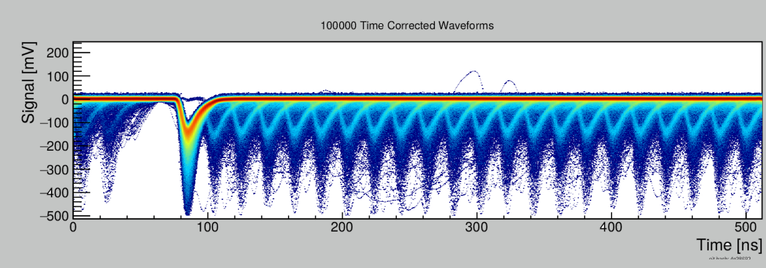
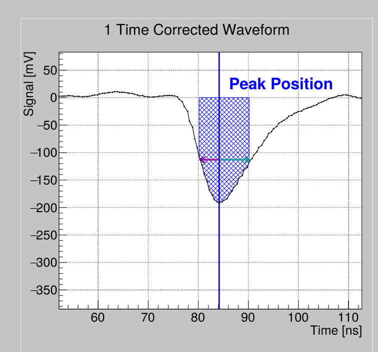
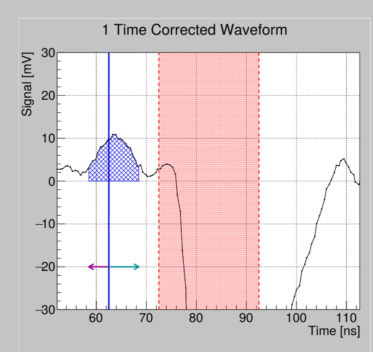


Figure: 100000 time corrected waveforms.

- signals in every bunch of the beam
- most dominant peak (@∼85 ns) → triggered signal
- no signals in pre-trigger bunch due to trigger dead time
- use this region to measure noise



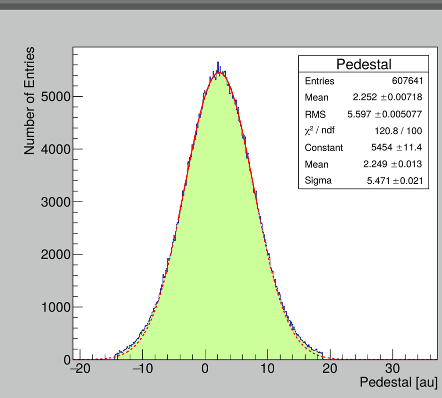
(a) Signal integration.



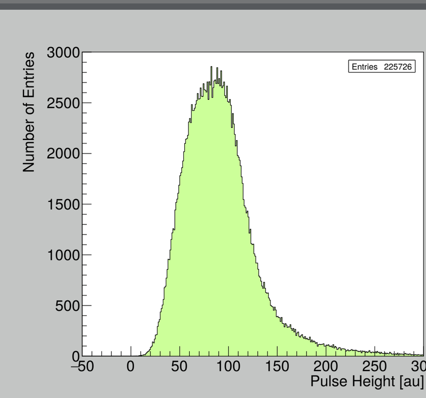
(b) Noise integration.

- find the triggered peak by max value
- signal: integrate asymmetrically around the peak
- noise: same integration window in centre of pre-trigger bunch
- final pulse height: signal - pedestal integral event by event

Results

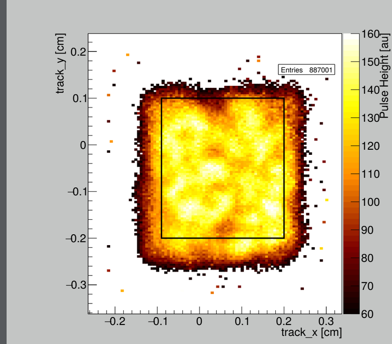


(a) Noise distribution

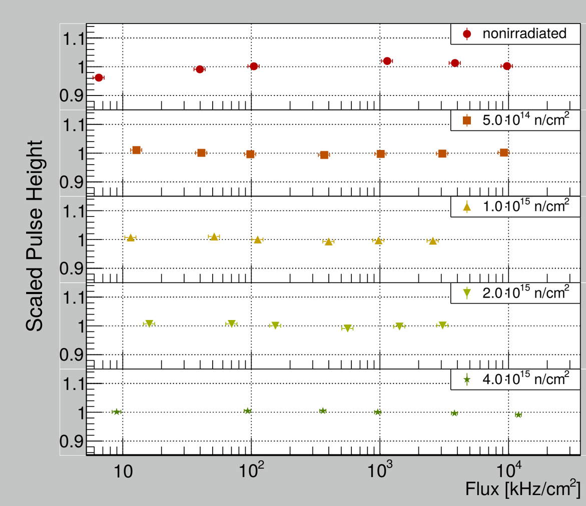


(b) Signal distribution.

- noise distribution agrees well with Gaussian even at high rates
- extract noise by taking the sigma of the Gaussian fit
- signal distribution Landau shaped
  - widened due to superimposition of many Landaus from different regions in the poly crystal



(a) Signal Map



(b) Pulse height vs. particle flux.

- regions with different pulse heights in pCVD diamond
- signals corresponding to wide Landau
- rate scaled to the mean
- pulse height very stable after irradiation

Conclusion

Pad Detectors:

- built beam test setup to characterise the rate behaviour of diamond pad detectors
- pCVD diamond show non-uniformity according to wide landau of the signal depending on the position in the diamond
- rate dependence for most non-irradiated pCVD <5 %
  - unknown origin, maybe surface contamination during production
  - possible to fix with surface treatment
- detectors with irradiated pCVD diamond sensors have a rate dependence below ∼2 % up to a flux of 20 MHz/cm^2

3D Detectors:

- 3D Detectors work well in pCVD diamond
- cell sizes down to 50 µm × 50 µm
- thin columns down to 2.6 µm
- general reasons for inefficiencies:
  - less charge in volume of the electrodes (0.4 % for shown devices)
  - missing/broken columns (0.2 % for the full device)
  - region with low electric field → need precise simulations
- (99.2 ± 0.3) % efficiency in 3 × 2 ganged device
- consistent mean charge measurements for all devices: ∼14 500 e
- largest charge collection of all pCVD diamond detectors